A short discussion about the Freezing of Photons as published in Nature Magazine recently.

Nobody ever thought that a Photon (A BOSON PARTICLE) could ever be frozen and can be solidified like any other matter. This is an impressive feat for the scientists who performed this experiment and many kudos to them. To comment on an experiment requires detailed knowledge about the processes involved as well as full knowledge about its outcome. I have no access to any of these, but as a layman reading the story in Nature Magazine felt tempted to write something for my friends just as a way of conversation.
It is evident from the stated facts that our knowledge about Photon is incomplete and there are more things about it, which are yet to come to light. Photon is a Quantum Particle, and its frozen state and solidification cannot be conceived of with our present knowledge. It is known to be of 0 rest mass and always moving. Its speed in complete vacuum is c (speed of Light in Vacuum) and is constant. Its speed in any other media is less than c. To capture a photon is very difficult and might be thought to be constrained in a small place by multiple reflections. But generally, it is never motion-less. About the phenomenon being discussed here, I make some assumptions or ideas about the type of experiment conducted.
. Recent research published in Nature demonstrates how photons can exhibit a state called supersolidity. This is a rare phase of matter where particles maintain a rigid structure like a solid but also flow without friction, like a superfluid.
In this ground-breaking study, scientists used a semiconductor platform to manipulate photons. By creating hybrid light-matter particles known as polaritons, they observed the formation of a super solid state. This involved unique spatial patterns and energy distributions that confirmed the presence of solid-like behaviour in light
Achieving superconductivity or frictionless states for photons typically requires ultra-controlled environments,

such as extreme cooling (near absolute zero) or high vacuum chambers. These conditions are necessary to maintain coherence and stability for quantum states like supersolidity or superfluidity. However, translating this science into practical, everyday use in harsher environments is a significant challenge which researchers must be actively tackling.

However, when achieving this state (Light-Matter interface) has been actually possible, it gives rise to many questions. What feature of Photons made it possible.? To explain this question in my way I will argue as follows.

Those who have read my previous articles (on Gravity) may remember that I made a postulation where the Universe is considered as a Double Domain system. This means the Primordial Energy at the beginning of the creation, being acted upon by an operator split into two domains----- 1st Domain consisting of Matter, Energy and all observable parts of the Universe being represented by a Ket Vector following Dirac's notation, and the 2nd Domain consisting of Space-Time and other intangible parts of the Universe like Dark Matter and Dark Energy being represented by a Bra-Vector as per Dirac's notation .In other words 1st Domain is the real part of the Universe, while the 2nd Domain forms the imaginary part (being associated with prefix i) of the Universe. Thus the total Universe is a complex quantity typically represented as a+ib.

I may mention here that this postulation may not be very farfetched. The equation of a plane wave is typically written as $y=Aei(wt-kx)$ where $k=2\pi/\lambda$, λ being the wave length. By expanding we can write it as $y=A\{Cos(wt-kx) + i\ Sin(wt-kx))$.

From above expression we see that the equation of a plane wave contains a real part and an imaginary part. Why is this so? Ostensibly it is because this equation is true for this whole universe, which has to be a complex quantity.

Now coming back to the case of Pho tons we have seen Photon freezing and solidification is a very unique occurrence for which there is not very clear explanation of the behaviour of the photon, under certain conditions. In

other words Photon must be having some features or characters which are hitherto unknown to us. I propose that Photon wave function be treated as a complex quantity like p+iq , instead of a real quantity, just like a wave equation which has both real and imaginary parts as shown above. The complex nature of the photon's wave function can indeed be a key factor. The wave function describes the probability amplitude of the photon's position and momentum, and its complex nature allows for interference and superposition—phenomena that are central to quantum mechanics. These properties enable photons to be manipulated in ways that seem counterintuitive, such as being slowed down, trapped, or even made to exhibit super solid behaviour.

In the experiments where photons were "frozen," researchers used advanced techniques to create hybrid light-matter particles called polaritons. These polaritons combine the properties of photons and matter, allowing scientists to manipulate them in ways that reveal new quantum states, such as supersolidity. The ability to control the photon's wave function and interactions with matter is what makes these breakthroughs possible.

Apart from this I have one more observation to make as follows:

The bending of light near massive objects, known as gravitational lensing, is explained by Einstein's General Theory of Relativity. According to this theory, massive bodies warp the fabric of spacetime, and light follows the curved paths within this warped spacetime. Importantly, photons—being massless—are not "attracted" by gravity in the classical sense like objects with mass are, but instead, their trajectory is altered because they follow the geometry of spacetime.

Now let us assume that laboratory environment like Ultra low temperature (within few degrees of absolute zero), formation of Bose Einstein condensate in sparse materials are naturally produced somewhere in the universe and quasi particles called polaritons formed out of photons

attributes small mass to the frozen or solidified photons. Now let us study its implications.

Regions very close to absolute zero might indeed occur in the universe. Consider the voids between galaxies or near certain celestial bodies where radiation is minimal. In such frigid and low-energy environments, matter behaves in unique ways, potentially forming states similar to Bose-Einstein condensates (BECs)—a state of matter where particles, like atoms, behave as a single quantum entity. If such condensate-like conditions were to arise naturally, photons interacting with these environments might exhibit unusual behaviours, including slowing down, becoming trapped, or forming quasi-particles like polaritons. This could lead to phenomena analogous to what we observe in controlled experiments, such as "freezing" photons.

These hypothetical natural condensates could also form around neutron stars, black holes, or within molecular clouds in deep space, where extreme gravitational, electromagnetic, and thermal conditions create unique quantum states. While we haven't yet observed such phenomena directly, they remain an exciting possibility in astrophysics and quantum cosmology. Now let us quantify our observations:

Potential Cosmic Environments for Natural Condensates

Deep Intergalactic Voids:

These vast, empty regions between galaxies are some of the coldest and quietest places in the universe, with minimal background radiation. The temperatures here can approach absolute zero (as cosmic microwave background radiation is only about 2.7 K).

Such low-energy environments could theoretically facilitate the creation of condensate-like states where light (photons) interacts with sparse matter in a manner that allows for slowed or trapped photons.

Molecular Clouds:

These are dense regions of gas and dust in space that serve as nurseries for star formation. Temperatures in these clouds can drop to just a few degrees above absolute zero.

Within these clouds, photons might interact with molecules and dust in ways that result in complex quantum states. This could potentially give rise to quasi-particles similar to polaritons, possibly leading to behaviors analogous to photon "freezing."

Near the Event Horizon of Black Holes:

Close to the event horizon, extreme gravitational forces create unique energy conditions. While the gravitational pull dominates, regions of lower energy density (due to shielding or interference effects) could arise, perhaps facilitating photon interaction with matter in unusual ways. This is purely speculative but aligns with the notion of extraordinary conditions fostering novel quantum behaviors.

Regions of Neutron Stars:

Neutron stars are incredibly dense and often emit extreme magnetic and gravitational forces. Surrounding these stars, there can be regions where energy dissipation and cooling occur, creating zones of low temperature and high density. These could be conducive to photon trapping or formation of exotic quantum states.

Possible Mechanisms for Photon Freezing in Nature

If such conditions exist, the natural environment might:

Act as a natural "trap" for photons, where interaction with particles or electromagnetic fields slows their motion.

Allow the creation of hybrid particles (like natural polaritons) via interaction with matter, altering the photons' effective properties.

Create localized low-energy pockets, much like laboratory setups, where photons behave as if they are in a condensate.

While much of this remains theoretical, it's fascinating to consider how the universe might naturally replicate phenomena we currently only observe in controlled lab experiments. The discovery of such environments would revolutionize our understanding of light, matter, and quantum mechanics.

If frozen photons, or more precisely quasi-particles like polaritons created from photons, acquire a small effective

mass in certain environments, they would indeed respond to gravitational forces like any other particle with mass. Even a tiny effective mass could result in noticeable deflection if the quasi-particle were near a very massive body, such as a star or a black hole. In such cases may be the deflection of light rays is due to gravitational attractions of massive bodies on polaritons near it. So curvature of Time-Space may not be applicable in such cases.

This is because gravitational force depends on mass, and the curvature of spacetime caused by massive objects would influence any particle with even the smallest mass. The greater the nearby mass, the more pronounced the deflection. This concept aligns with Newtonian gravity and relativistic principles.

However, it’s worth noting that these quasi-particles exist only under very specific conditions, such as in engineered systems like superfluid-like environments or in condensed matter physics experiments. Outside of these controlled environments, the photons themselves revert to being massless, meaning the curvature of spacetime (general relativity) remains the prevailing explanation for their path deflection.